Considerations for mounting the dove prism in the reference beam of the Long Trace Profiler

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1. Introduction

The usual way that a mirror is mounted in the Long Trace Profiler[1] (LTP) is such that the mirror's surface normal points upward, so that the probe beam pair (or just 'beam') from the LTP initially heads downward toward the mirror surface under test (SUT) and then reflects up into the LTP optical system. At the same, time a reference (REF) beam reflects from an external mirror in order to monitor slope errors resulting from the carriage pitch movement[2]. In December, 1992 a dove prism was inserted in the REF beam in order to compensate for carriage yaw errors if the mirror was to be measured in the horizontal orientation[3,4]. In August, 1993 it was discovered that the error from laser pointing instability was not compensated for by the external reference, but rather was increased. This is because the laser pointing error moves in one direction for the SUT beam, but in the opposite direction for the REF beam. Thus, as the carriage pitch error from the REF is subtracted from the SUT, the laser pointing error from the REF is added to the SUT. This problem was fixed by setting a beamsplitter on the carriage, giving an internal reference which compensated for the laser pointing error separately; this required three slope functions. In 1994, Bresloff and Takacs[5] replaced this beamsplitter with a dove prism on the carriage, in order to reverse the direction of the laser pointing errors. Then the laser pointing errors were in the same direction as the carriage pitch errors, and as before only two slope functions were required.

This paper intends to generalize the problem of carriage pitch errors, carriage yaw errors, and laser pointing errors, and to formulate a procedure for proper dove prism mounting that will compensate for these errors when the mirror is mounted with respect to the LTP either vertically or horizontally.

2. Analysis

Figure 1 shows a schematic of the main optical components inside and outside the carriage. We first analyze the angle changes that the beams make as they propagate through the LTP optical system without the dove prism. Then we consider different ways of inverting the beam direction using a dove prism so that the laser pointing error may be subtracted along with the carriage pitch or yaw error.

2.1 Angle changes with no dove prism

Figure 1 shows the LTP system with only SUT and REF beams. The beam from the source S is split by beamsplitter BS into the REF and SUT beams. If the carriage pitches clockwise (CW), then the beam from the SUT will move counterclockwise (CCW); reflection

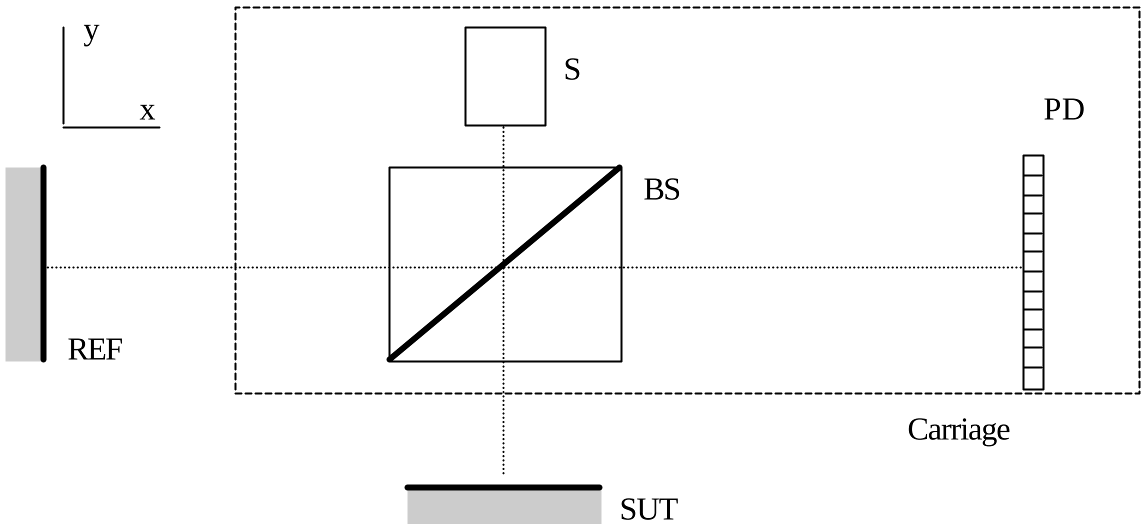

Figure 1. LTP optical system schematic.

from BS gives a CW motion to the beam. The effect of a CW pitch by BS (because the carriage pitches) is canceled by a likewise rotation of photodetector array PD. Thus, a CW motion of the carriage results in a CW motion of the beam on PD via the SUT. This analysis is simplified by considering only a relative movement of the REF and SUT mirrors. A CW pitch of the carriage is relatively the same as the SUT and REF each moving CCW through the same angle. As the REF moves CCW, the beam at PD moves CCW. Therefore, compensation for carriage pitch error would be performed by adding the SUT and REF slope functions:

$$s(x) = SUT(x) + REF(x). \tag{1}$$

A CW laser pointing change of the beam from source S would give a CCW change to the beam after reflection from the SUT and then a CW change to the beam after reflection from BS. Thus, a CW motion of the beam from S results in a CW motion of the beam on PD via the SUT. A CW change of the beam from S, however, would give a CCW change of the beam after BS, and a CW change after reflection from the REF, which would give a CW change at PD. Therefore, compensation would be performed by subtracting the SUT and REF slope functions:

$$s(x) = SUT(x) - REF(x). \tag{2}$$

Clearly both Equations (1) and (2) cannot be performed, so either carriage pitch error or laser pointing error may be removed, but not both.

2.2 Angle changes with a dove prism in the SUT beam

Figure 2 shows a dove prism mounted in the SUT beam. A dove prism reverses the angles of light rays in the meridional plane (the plane of this paper). Therefore, a CW change of the beam at S will give a CCW change of the beam coming out of dove prism D. The beam will change CW upon reflection at the SUT, and then CCW after passing again through D; the beam will change CW reflecting from BS. Thus, PD will see a CW change from a CW laser pointing error via the SUT. Meanwhile, a CW change at S will give a CCW change at BS, and a CW change after reflection from the REF; PD then sees a CW change via the REF. Error compensation is accomplished by subtracting the two slope functions:

$$s(x) \quad = \quad SUT(x) \ - \ REF(x). \tag{2}$$

As before, a CW carriage pitch is equivalent to a CCW SUT rotation, giving a CCW change to the beam. This beam change is made CW after passing through D, and then CCW after reflecting from BS. A CCW rotation of the REF results in a CCW beam change at PD. Therefore, since the beam changes via SUT and REF are both CCW, the functions are subtracted:

$$s(x) \quad = \quad SUT(x) \ - \ REF(x). \tag{2}$$

Both carriage pitch and laser pointing errors are removed by Equation (2).

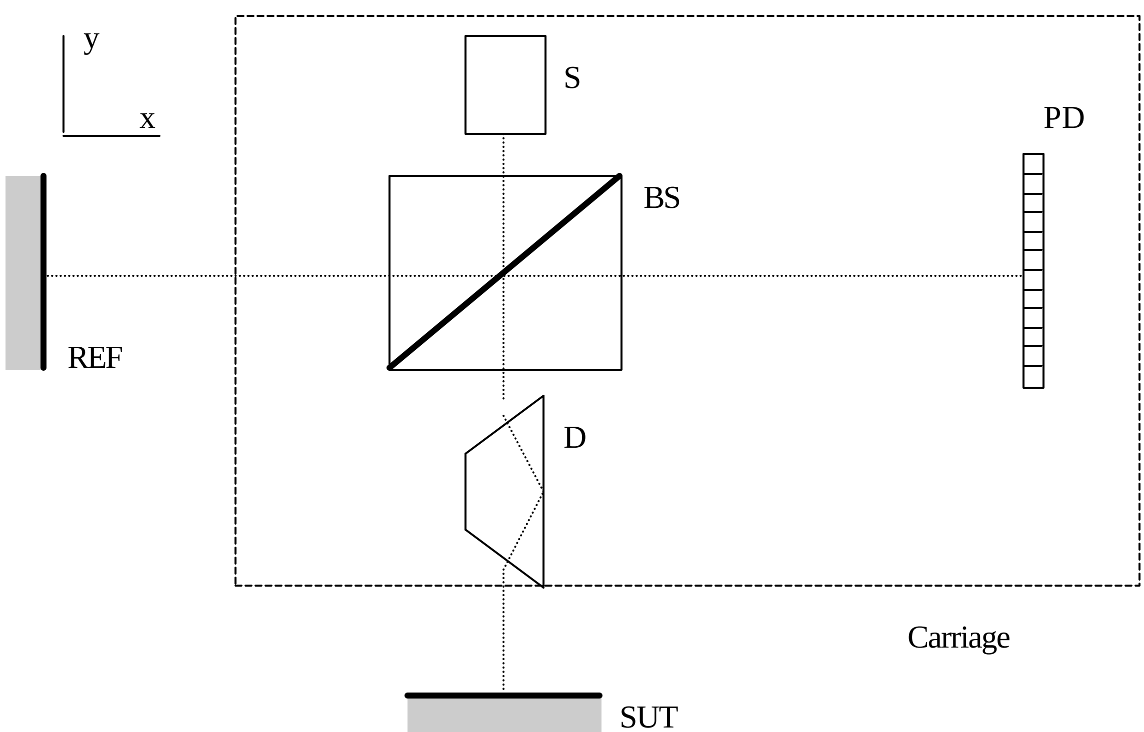

Figure 2. Dove prism in the SUT beam path.

A compact notation may be used to describe the angle changes that the beams experience as they propagate through the system. Using standard notation for a right-handed coordinate system, let us denote a CW change in beam pointing at S in the xy plane by "-z". (This is a negative rotation about the z axis at S). We then list all the subsequent angle changes through the system for the case of the dove prism in the SUT beam:

laser pointing change				carriage pitch			
SUT path		REF path		SUT path		REF path	
S	-z	S	-z	SUT	+z	REF	+z
D	+z	BS	+z	D	-z		
SUT	-z	REF	-z	BS	+z		
D	+z						
BS	-z						

The final angle changes for laser pointing change at PD (same as after BS in the SUT path and REF in the REF path) are both -z. For carriage pitch the angle changes at PD are also the same in both the SUT path and the REF path. Thus, Equation (2) (subtraction) must be used for both laser pointing change and carriage pitch.

2.3 Angle changes with a dove prism in the REF beam

Figure 3 shows a dove prism mounted in the REF beam. Starting with a CW change of the beam at S and a CW carriage pitch, compact notation gives:

laser pointing change				carriage pitch			
SUT path		REF path		SUT path		REF path	
S	-z	S	-z	SUT	+z	REF	+z
SUT	+z	BS	+z	BS	-z	D	-z
BS	-z	D	-z				
		REF	+z				
		D	-z				

In this case, too, both carriage pitch and laser pointing errors are removed by Equation (2).

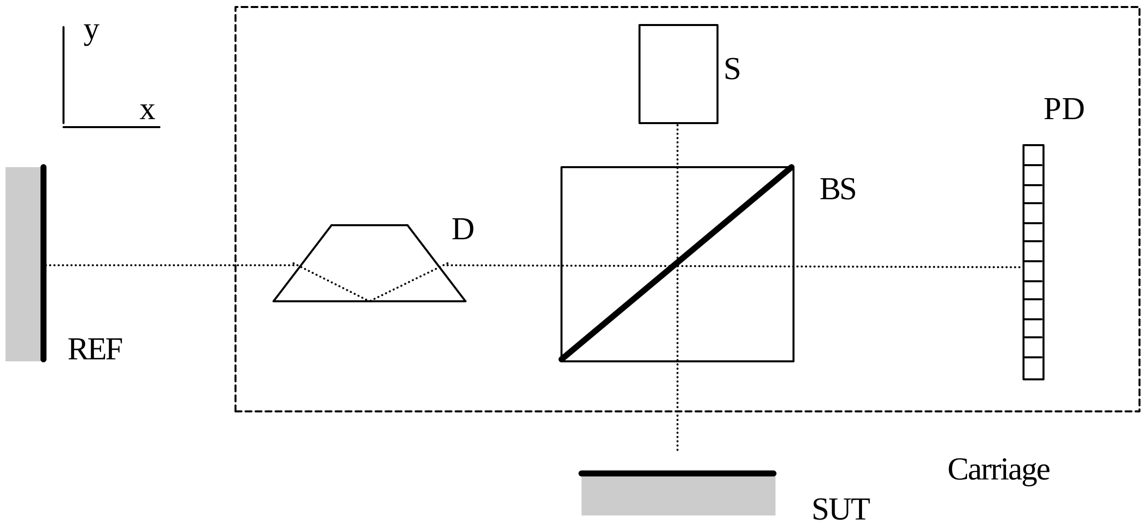

Figure 3.   Dove prism in the REF beam path.

2.4 Angle changes produced by carriage yaw error

When the mirror is mounted horizontally, the beam from the carriage must be bent 90 degrees so that it is normal to the SUT. This is best achieved with a pentaprism PP, as shown in Figure 4. A pentaprism maintains a 90 degree angle between the input and output beams with insignificant effect from carriage pitch or yaw. In the previous cases (sections 2.2, 2.3, 2.4) we were interested in measuring slope changes in the xy plane with respect to x. Now we are interested in measuring slope changes in the xz plane with respect to x. The pentaprism bends the beam in the yz plane; angle changes in the xy plane and xz plane are unaffected by the pentaprism, except that they are bent 90 degrees.

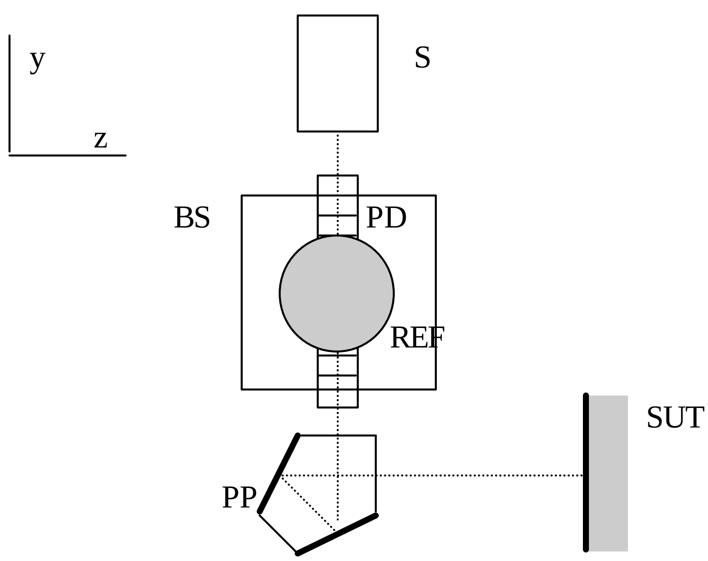

Figure 4. Using a pentaprism for horizontal mirror mounting.

Figure 5 shows a top view of the carriage. Carriage yaw is a rotation in the plane of the paper in this case, and will give slope measurement error for the SUT mounted horizontally. (Carriage pitch only rotates the probe beam pair at the SUT an insignificant amount.) Carriage yaw is compensated for by setting a dove prism on the carriage in such an orientation that the probe beam pair going to the REF mirror is rotated 90 degrees. This is accomplished by rotating the dove prism with respect to the carriage by 45 degrees about the x axis. The beam then emerges from the dove prism D with a beam pair which detects angle changes in the xz plane.

Should the dove prism be rotated 45 degrees CW or CCW? The analysis can be confusing if we consider rotating the dove prism, but much easier if we first consider rotating the beam pair with respect to the dove prism. Figure 6 shows a beam pair incident on a dove prism (solid lines), and the beam pair emerging from the prism (dashed lines). The parts of the beams are labeled so that we may keep track of how the beam changes direction. The rules for tracing a ray through the dove prism are:

1. The direction of the ray around the σ axis is reversed with respect to the $x\sigma$ plane in the dove prism aperture.
2. The position component of the ray in the ρ direction in the dove prism aperture is reversed with respect to the $x\sigma$ plane.
3. The direction of the ray around the ρ axis is unaffected. It emerges in the direction that it enters.
4. The position component of the ray in the σ direction is unaffected.

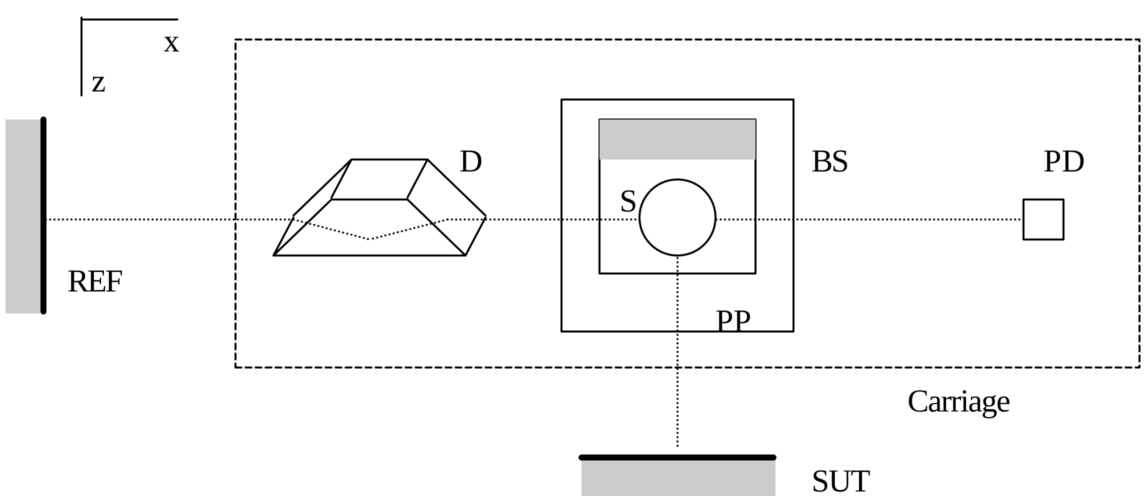

Figure 5. Top view of the LTP with the mirror mounted horizontally.

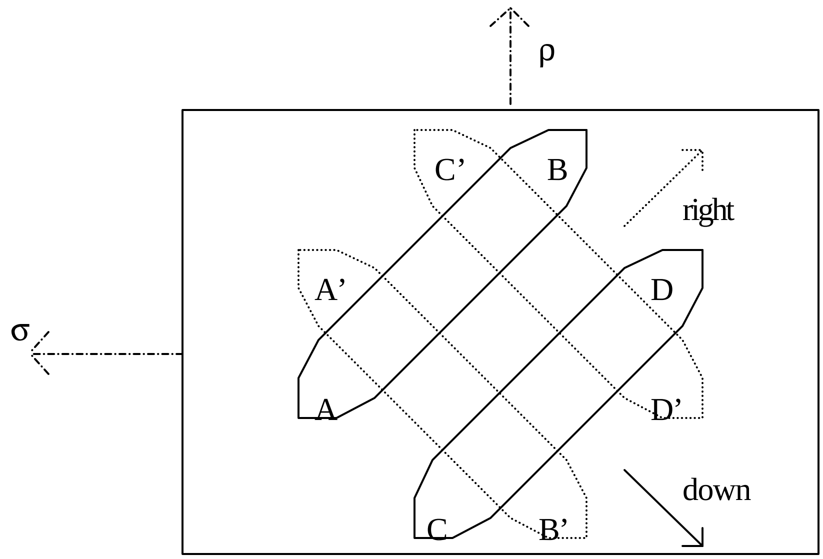

Figure 6. End view of dove prism with input, output beam pairs shown.

2.5 Angle changes with a dove prism in the REF beam at 45 degrees CW

Looking along the x axis in the direction of decreasing x, suppose the dove prism is rotated 45 degrees CW, as is shown in Figure 5. Then the beam pair will be incident on the dove prism as in Figure 6 (solid lines). Following the rules given above, the end of the beam labeled A will exit the prism at A', and so forth, which will rotate the exiting beam pair about the x axis by 90 degrees. Also, a downward angle change in the xy plane (CCW from BS) of the input beam pair (shown by the solid arrow) will result in a rotation of the exiting beam to the right (shown by the dotted arrow). Using standard notation for a right-handed coordinate system, we say that the input beam is rotated in the +z direction, and the output beam is rotated in the -y direction. Reflection from REF results in an angle change of +y. The entire system for CW carriage yaw is as follows.

laser pointing change				carriage yaw			
SUT path		REF path		SUT path		REF path	
S	-z	S	-z	SUT	+y	REF	+y
PP	-y	BS	+z	PP	+z	D	-z
SUT	+y	D	-y	BS	-z		
PP	+z	REF	+y				
BS	-z	D	-z				

Equation (2) would be used for both laser pointing change and carriage yaw. Thus, the dove prism could be rotated 45 degrees CW for proper compensation. Does rotating the dove prism 45 degrees in the opposite direction yield the same result?

2.6 Angle changes with a dove prism in the REF beam at 45 degrees CCW

Now suppose the dove prism is rotated CCW with respect to the x axis, looking in the direction of decreasing x. (This is rotation in the +x direction.) The analysis is as follows.

laser pointing change				carriage yaw			
SUT path		REF path		SUT path		REF path	
S	-z	S	-z	SUT	+y	REF	+y
PP	-y	BS	+z	PP	+z	D	+z
SUT	+y	D	+y	BS	-z		
PP	+z	REF	-y				
BS	-z	D	-z				

Equation (2) would be used for laser pointing change, while Equation (1) must be used for carriage yaw compensation. This is an unacceptable solution.

2.7 A system for measuring a downward pointing surface

Figure 7 shows a second pentaprism for bending the probe beam pair upward, so that a surface that is pointing downward may be measured. Again we are interested in measuring slope

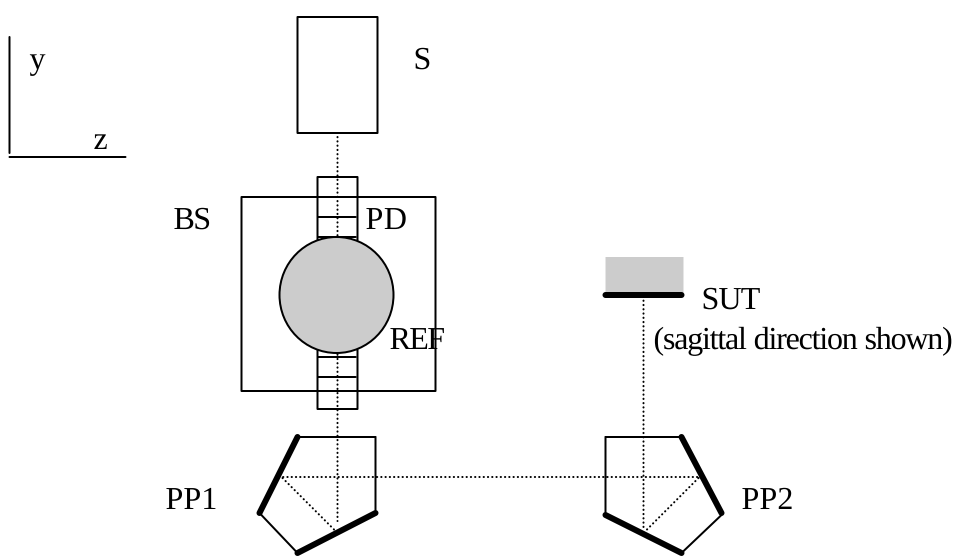

Figure 7. Using two pentaprisms for downward mirror mounting.

changes in the xy plane with respect to x, and carriage pitch is the significant source of error. The analysis for this system is as follows.

laser pointing change				carriage pitch			
SUT path		REF path		SUT path		REF path	
S	-z	S	-z	SUT	+z	REF	+z
PP1	-y	BS	+z	PP2	-y		
PP2	+z	REF	-z	PP1	-z		
SUT	-z			BS	+z		
PP2	+y						
PP1	+z						
BS	-z						

Notice that this systems requires no dove prism, and Equation (2) is used for both laser pointing change and carriage pitch compensations. Putting a dove prism in any beam path will give an unacceptable solution.

Actually, two mirrors could be used instead of two pentaprisms with this mounting. This notation can also be used to satisfy the reader that a concave surface pointing downward is measured as concave by the LTP.

3. Summary

Error compensation for both laser pointing change and carriage pitch or yaw may be compensated for by a single dove prism. For carriage pitch, the dove prism may be placed in either the SUT path or the REF path with satisfactory results. Although placing the dove prism in the SUT path for carriage yaw was not mentioned, it would be uneconomical to do so, and the added torque of the prism on the carriage increases the risk of damage to the LTP air bearing. Therefore, the best arrangement is for the dove prism to be placed in the REF beam path as shown in Figure 3 (for vertical mirror mounting) or Figure 5 (for horizontal mirror mounting).

For vertical mounting with the SUT pointing downward, no dove prism is used.

4. References

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2. Irick, S. C., McKinney, W. R., Lunt, D. L. J., and Takacs, P. Z., "Using a straightness reference in obtaining more accurate surface profiles from a long trace profiler," **Review of Scientific Instruments**, vol. 63, No.1 (Part IIB), 1436-1438, (January, 1992).

3. Irick, S. C., “LTP Side-looking measurements”, “Dove prism mounting block”, **Lawrence Berkeley Laboratory Engineering Note**, 16 December, 1992.

4. Irick, S. C., “Measurement of a round-robin flat mirror with a Long Trace Profiler in both horizontal and vertical mountings”, **ALS Beamline Note** LSBL-286, 18 September, 1995.

5. Takacs, P. Z., Bresloff, C. J., "Significant Inprovements in Long Trace Profiler Measurement Performance", **Proc. SPIE**, Vol. 2856, Optics for High Brightness Synchrotron Radiation Beamlines II, (1996) 236-245.